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Interior Douglas-fir Growth Intercept Models

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Abstract

The objective of this study was to develop growth intercept models for interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). These models relate site index to the early height growth of trees. They were developed using a well-established modelling technique and 72 sample plots established throughout the interior of British Columbia, and were tested with an independent data set. The test showed that the models were statistically biased below breast height age nine, but the practical significance of the bias may be such that the models can be used in young stands. The results of the model testing should be interpreted with caution.

Introduction

Growth intercept models relate site index to the early height growth of trees on a site, and therefore allow site index to be estimated from height growth. These models are now becoming a standard tool for estimating site index. They are currently used in silviculture surveys (B.C. Ministry of Forests 1995), paired-plot sampling (B.C. Ministry of Forests 1996), and inventory audits (B.C. Ministry of Forests 1997). Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) is a common species in dry areas of British Columbia (Meidinger and Pojar 1991). Therefore, development of a growth intercept model for Douglas-fir is considered a moderately high priority.

Data

The model-development data consist of 72 stem-analysis sample plots. Fifty plots[1] were established in 1995 and the remaining plots[2] were established in 1996 to better cover the upper and, more significantly, lower ranges of site index. The 363-m^2 plots were established in the Interior Cedar-Hemlock (ICH), Interior Douglas-fir (IDF), Montane Spruce (MS), and Sub-Boreal Spruce (SBS) biogeoclimatic zones (Meidinger and Pojar 1991). Three top height trees from each plot were intensively sampled by measuring the height of each tree, as identified by annual branch whorls, at breast height ages 0–50. The tree heights were averaged by breast height age to give top height by breast height age for each plot. The growth intercept and site index were then calculated using equations 1 and 2, respectively.

1. J.S. Thrower and Associates Ltd. 1995. Interior Douglas-fir growth intercept project data package. Res. Br., B.C. Min. For., Victoria, B.C. Unpubl. rep.
2. J.S. Thrower and Associates Ltd. 1996. Data collection for interior Douglas-fir growth intercepts on high and low productivity sites. Res. Br., B.C. Min. For., Victoria, B.C. Unpubl. rep.

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$$GI_{i,A} = \frac{H_{i,A} - 1.3}{A - P_i} \times 100. \quad (1)$$

$$SI_i = H_{i,50}, \quad (2)$$

where:

$GI_{i,A}$ = growth intercept (cm/yr) for plot i at breast height age A,
$H_{i,A}$ = top height (m) of plot i at breast height age A,
A = breast height age (years),
P_i = proportion of growth between breast height ages 0 and 1 that occurred below breast height for plot i, and
SI_i = site index (m) of plot i.

The test data consist of 38 sample plots from the IDF and ICH biogeoclimatic zones (Thrower and Goudie 1992). Four trees in each 0.04-ha plot were sectioned. The height–ring count data from the sections were converted into height–breast height age data following the procedures described in Nigh (1995). The site index and growth intercepts between breast height ages 1 and 50 were calculated from equations 1 and 2.

Methods

The data analysis proceeded the same way as described in Nigh (1997a). The growth intercept model is given in equation 3.

$$SI_i = 1.3 + e^{b_0} \times GI_{i,A}^{b_1} + \varepsilon_i \quad (3)$$

where:

b_0, b_1 = model parameters, and
ε_i = the error term for plot i.

This model was fitted to the data using nonlinear least-squares regression. The fitting was done for each breast height age between 1 and 50, resulting in 50 models. Tests were performed on each model to ensure that the standard regression assumptions (Sen and Srivastava 1990) were met and that the model behaved close-to-linearly (Ratkowsky 1983). Residual plots also helped to assess the model assumptions.

The models were tested with an independent data set by first calculating the error in estimated site index (actual site index minus estimated site index) for each plot and breast height age between 1 and 50. The errors were then averaged by age and a 95% confidence interval for the mean error was computed. The mean error and its 95% confidence interval were plotted against breast height age.

Results

Table 1 presents the growth intercept models and their root mean square error, which is a measure of the accuracy of the model. The graphs and tests show that the residuals are normally distributed, homoscedastic, and have a mean which is not significantly different from zero. The regression assumptions are therefore met. Tests for nonlinearity show that the models behave in a close-to-linear fashion.

The model testing shows that the models for breast height ages of less than nine are significantly different from zero and may be biased (Figure 1). However, the estimated bias is greater than 1 m only for breast height ages of less than six.

Discussion and Conclusion

This study produced a set of growth intercept models for interior Douglas-fir (Table 2). When compared to the models for other interior species (Nigh 1996, 1997b), the Douglas-fir models are less precise. This implies that the recommended minimum age used in growth intercept surveys for site index should be greater for Douglas-fir than for other interior species. As well, older stands should be sampled to achieve a specified precision. Table 2 illustrates that, as expected, the site index estimates are not exact at breast height age 50. This anomaly is caused by slight deviations from the assumption that the trees in

TABLE 1 *Interior Douglas-fir growth intercept models for breast height ages 1 to 50*

Age[a]	Model	RMSE[b]	Age	Model	RMSE
1	$\hat{SI} = 1.3 + 4.114 \times GI_{1}^{0.4540}$	3.855	26	$\hat{SI} = 1.3 + 0.6355 \times GI_{26}^{0.9066}$	1.389
2	$\hat{SI} = 1.3 + 3.312 \times GI_{2}^{0.5139}$	3.594	27	$\hat{SI} = 1.3 + 0.6273 \times GI_{27}^{0.9105}$	1.335
3	$\hat{SI} = 1.3 + 2.365 \times GI_{3}^{0.6037}$	3.294	28	$\hat{SI} = 1.3 + 0.6182 \times GI_{28}^{0.9148}$	1.261
4	$\hat{SI} = 1.3 + 1.830 \times GI_{4}^{0.6683}$	3.097	29	$\hat{SI} = 1.3 + 0.6067 \times GI_{29}^{0.9204}$	1.208
5	$\hat{SI} = 1.3 + 1.589 \times GI_{5}^{0.7005}$	2.955	30	$\hat{SI} = 1.3 + 0.5957 \times GI_{30}^{0.9261}$	1.140
6	$\hat{SI} = 1.3 + 1.461 \times GI_{6}^{0.7186}$	2.901	31	$\hat{SI} = 1.3 + 0.5826 \times GI_{31}^{0.9326}$	1.061
7	$\hat{SI} = 1.3 + 1.327 \times GI_{7}^{0.7395}$	2.856	32	$\hat{SI} = 1.3 + 0.5714 \times GI_{32}^{0.9385}$	1.007
8	$\hat{SI} = 1.3 + 1.237 \times GI_{8}^{0.7545}$	2.750	33	$\hat{SI} = 1.3 + 0.5665 \times GI_{33}^{0.9417}$	0.9445
9	$\hat{SI} = 1.3 + 1.203 \times GI_{9}^{0.7575}$	2.656	34	$\hat{SI} = 1.3 + 0.5509 \times GI_{34}^{0.9503}$	0.8908
10	$\hat{SI} = 1.3 + 1.127 \times GI_{10}^{0.7717}$	2.598	35	$\hat{SI} = 1.3 + 0.5422 \times GI_{35}^{0.9556}$	0.8219
11	$\hat{SI} = 1.3 + 1.071 \times GI_{11}^{0.7819}$	2.570	36	$\hat{SI} = 1.3 + 0.5342 \times GI_{36}^{0.9607}$	0.7745
12	$\hat{SI} = 1.3 + 0.9716 \times GI_{12}^{0.8049}$	2.439	37	$\hat{SI} = 1.3 + 0.5290 \times GI_{37}^{0.9646}$	0.7172
13	$\hat{SI} = 1.3 + 0.9143 \times GI_{13}^{0.8188}$	2.360	38	$\hat{SI} = 1.3 + 0.5225 \times GI_{38}^{0.9691}$	0.6678
14	$\hat{SI} = 1.3 + 0.8701 \times GI_{14}^{0.8300}$	2.272	39	$\hat{SI} = 1.3 + 0.5179 \times GI_{39}^{0.9728}$	0.6212
15	$\hat{SI} = 1.3 + 0.8495 \times GI_{15}^{0.8347}$	2.193	40	$\hat{SI} = 1.3 + 0.5061 \times GI_{40}^{0.9802}$	0.5659
16	$\hat{SI} = 1.3 + 0.8215 \times GI_{16}^{0.8419}$	2.137	41	$\hat{SI} = 1.3 + 0.5003 \times GI_{41}^{0.9847}$	0.5067
17	$\hat{SI} = 1.3 + 0.8013 \times GI_{17}^{0.8472}$	2.064	42	$\hat{SI} = 1.3 + 0.4957 \times GI_{42}^{0.9887}$	0.4467
18	$\hat{SI} = 1.3 + 0.7880 \times GI_{18}^{0.8508}$	1.994	43	$\hat{SI} = 1.3 + 0.4936 \times GI_{43}^{0.9912}$	0.3917
19	$\hat{SI} = 1.3 + 0.7722 \times GI_{19}^{0.8553}$	1.916	44	$\hat{SI} = 1.3 + 0.4931 \times GI_{44}^{0.9930}$	0.3351
20	$\hat{SI} = 1.3 + 0.7532 \times GI_{20}^{0.8613}$	1.836	45	$\hat{SI} = 1.3 + 0.4927 \times GI_{45}^{0.9946}$	0.2854
21	$\hat{SI} = 1.3 + 0.7274 \times GI_{21}^{0.8703}$	1.753	46	$\hat{SI} = 1.3 + 0.4875 \times GI_{46}^{0.9988}$	0.2354
22	$\hat{SI} = 1.3 + 0.7204 \times GI_{22}^{0.8728}$	1.671	47	$\hat{SI} = 1.3 + 0.4866 \times GI_{47}^{1.001}$	0.1849
23	$\hat{SI} = 1.3 + 0.6862 \times GI_{23}^{0.8858}$	1.616	48	$\hat{SI} = 1.3 + 0.4857 \times GI_{48}^{1.002}$	0.1370
24	$\hat{SI} = 1.3 + 0.6790 \times GI_{24}^{0.8886}$	1.548	49	$\hat{SI} = 1.3 + 0.4899 \times GI_{49}^{1.002}$	0.08602
25	$\hat{SI} = 1.3 + 0.6583 \times GI_{25}^{0.8972}$	1.468	50	$\hat{SI} = 1.3 + 0.4950 \times GI_{50}^{1.000}$	0.04920

a Age at breast height = number of annual growth rings at breast height.
b RMSE = root mean square error.

TABLE 2 *Estimated site indices from the interior Douglas-fir growth intercept model*

| Age[a] (yrs) | Tree height (m) | | |

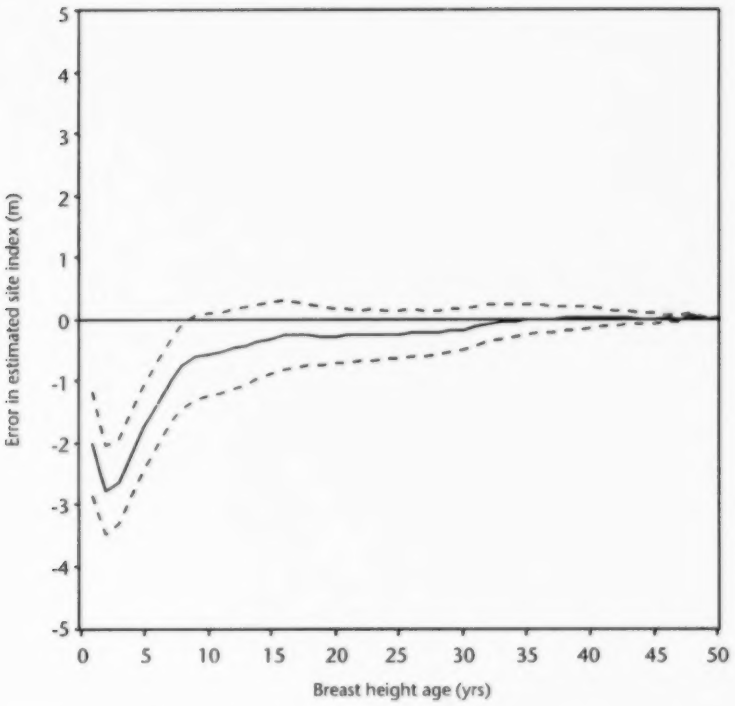

FIGURE 1 *Graph of mean error (—) as a function of breast height age with 95% confidence interval (– – –).*

the model development data have, on average, 49.5 years of height growth above breast height at breast height age 50.

The model testing revealed that those for breast height ages under nine may be biased. This may be acceptable depending on the magnitude of the bias, the application, and other alternatives for estimating site index. However, the results of the testing must be treated with some caution. A model is a reflection of the data from which it is developed. If testing with an independent data set shows that a model is biased, then it may be that one (or both) of the data sets is biased. A graphical analysis shows that the Douglas-fir model development and test data are quite different at young ages. Based on the experience of the sampling crew and the sampling protocol that was followed, the model development data for this project are of higher quality than the test data. Therefore, the model development data probably better represent the stands in which the models will be applied. However, further testing of the models should be done.

A growth intercept model for Douglas-fir that is applicable across the interior of British Columbia is now available. Sampling for this model covered the major interior ecosystems that support Douglas-fir. More data should be obtained to complete the coverage and to further test the models.

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